HYPERACCUMULATION OF NICKEL BY *ARENARIA RUBELLA* (CARYOPHYLLACEAE) FROM WASHINGTON STATE

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Abstract

The nickel concentration of whole plants of **Arenaria rubella** collected on dunite, Skagit County, Washington, U.S.A., is reported as 1360 $\mu g\ g^{-1}$ (dry weight), compared with only 2.7 $\mu g\ g^{-1}$ for specimens collected on shale, Jefferson County. This is the first hyperaccumulator of nickel reported from northwestern North America. High concentrations of chromium, cobalt and iron at 213, 33.5 and 28,900 $\mu g\ g^{-1}$, respectively, in plants from dunite contrast with low values (3, 0.49 and 600 $\mu g\ g^{-1}$) in samples from shale.

During the past 20 years many taxa, mostly endemic to the nickel-rich soils derived from ultramafic outcrops, have been reported as accumulating nickel in high concentrations (Brooks et al. 1977; Peterson 1983; Brooks 1987). Such plants have been termed "hyperaccumulators" when containing $> 1000\ \mu g\ g^{-1}$ Ni (dry weight) (Brooks et al. 1977). The term, hyperaccumulator, should not be thought to infer a physiological or biochemical basis for high values of metal uptake. Rather, it simply serves to indicate unusually high concentrations in plant tissues. Hyperaccumulator plants, then, exemplify one specialized consequence of living in a heavy metal environment.

The numerous reports from several countries on metal concentrations in plants from ultramafic soils have been based primarily on samples from herbarium specimens. Thus, the first hyperaccumulator of nickel in North America, *Streptanthus polygaloides* Gray, with 9750 $\mu g\ g^{-1}$, was detected in this manner (Reeves et al. 1981, 1983). We report here an instance of hyperaccumulation of nickel based on field-collected samples. We found *Arenaria rubella* (Wahlenb.) J. E. Smith to be the only hyperaccumulator in tests of 42 species of flowering plants, conifers and ferns collected on ultramafics in Washington state. Appendix 1 lists those plants found not to be hyperaccumulators.

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Materials and Methods

Samples of whole plants were collected at two sites on ultramafic rock and one on shale. The *Arenaria rubella* samples of ultramafics came from a large dunite deposit (the Twin Sisters dunite) at the Olivine Bridge Natural Area, South Fork Nooksack River, Skagit County, elevation 540 m (1900 ft). Dunite is an ultramafic igneous rock consisting of the iron-magnesium silicate mineral, olivine; nickel and chromium are commonly found in dunite. Soils derived from dunite and serpentinite are azonal (skeletal), shallow and with no profile development. Two samples of soil (Kruckeberg nos. 6660 and 6662) were collected for chemical analysis (Table 2). The soils were air-dried and separated into 2 mm and coarse fractions. Replicate samples were analyzed for nickel, chromium, cobalt, iron, magnesium and calcium by atomic absorption spectrophotometry using the techniques described below for tissues; less than 2 mg of each sample was used in each determination.

The dunite conglomerate at Olivine Bridge supports a sparse stand of stunted conifers: *Pseudotsuga menziesii* (Douglas fir), *Pinus contorta* (lodgepole pine), *P. monticola* (western white pine) and *Juniperus communis* (common juniper). On intervening barren areas only a few widely spaced herbs grow: *Arenaria rubella, Cerastium arvense, Aspidotis densa* and *Achillea millefolium* (Kruckeberg 1969). Nearby non-ultramafic sites support typical second-growth mixed conifer-hardwood stands. The samples were taken on 22 September 1980 and on 27 July 1981.

The *Arenaria rubella* samples from a shale outcrop were collected on 22 August, 1981 at Buckhorn Pass at 1500 m (5000 ft) in the northeastern sector of the Olympic Mountains, Jefferson County, Washington, in a subalpine fellfield. This locality is in the midst of an *Abies lasiocarpa* (subalpine fir)-parkland habitat with a rich grass/forb cover.

Samples of *Arenaria obtusiloba* (Rydb.) Fern. were taken on 4 September 1980 on serpentinized peridotite along Eldorado Creek, upper North Fork Teanaway River, Kittitas County. The site is in an open, mixed conifer forest with Douglas fir, lodgepole pine, western white pine, *Pinus ponderosa* (yellow pine), *P. albicaulis* (whitebark pine) and common juniper (Kruckeberg 1969). *Arenaria obtusiloba* grew on barren talus and on ridges as widely scattered individuals. It occurs with *Aspidotis densa, Douglasia nivalis* var. *dentata, Polystichum lemmonii, Poa curtifolia, Lomatium cuspidatum* and *Chaenactis thompsonii*; the latter four species are serpentine endemics in the Wenatchee Mountains (Kruckeberg 1969).

Ten individuals were collected at each of the four sites, including two different dunite locations at Olivine Bridge. Entire rosettes of separate but neighboring individuals were chosen at a given site.

Whole-plant samples (roots and shoots) were prepared for analysis by washing in distilled water and drying to constant weight at 70°C. The whole plants were powdered in a commercial (Braun) mill and 2 g subsamples were dry ashed at 450°C until all traces of organic matter had disappeared. The ash was leached with hot 2 M HCl and diluted to 10 ml. Samples were analyzed for nickel, chromium, cobalt, iron, magnesium and calcium by atomic absorption spectrophotometry using a Varian Techtron Mark 5 flame atomic absorption spectrophotometer. Nickel analyses were performed at a wavelength of 231.7 nm with an air-acetylene mixture and oxidizing flame stoichiometry (Shewry and Peterson 1976).

Results and Discussion

The analytical data for *Arenaria rubella* collected from an ultramafic and a nonultramafic site are presented in Table 1 together with data for *A. obtusiloba.* Higher concentrations of nickel, chromium, cobalt, iron and magnesium and lower concentrations of calcium occur in plants from the dunite outcrop compared with those collected on shale. The high nickel concentration in *A. rubella* puts it in the hyperaccumulator category.

The nickel concentration in *A. rubella* (1360 $\mu g\ g^{-1}$) on dunite is approximately one half the total soil nickel concentration of 2643 $\mu g\ g^{-1}$ (dry weight; Table 2). When expressed on an ash weight basis, plant nickel concentration greatly exceeds soil nickel. On a dry weight basis, the 5260 $\mu g\ g^{-1}$ calcium concentration in plants exceeds the soil concentration of 1944 $\mu g\ g^{-1}$ indicating that soil contamination is unlikely to be a significant source of analytical error. The Ca:Mg ratio for *A. rubella* of 0.08 lies within the range of values recorded for other species on serpentine soils (Shewry and Peterson 1976).

Although *A. rubella* is a widely distributed circumpolar species, it seems likely that the specimens collected from the dunite site are from a serpentine race, physiologically but not morphologically, different from the non-serpentine race. *Arenaria rubella* is known from ultramafic sites on the Gaspé Peninsula of eastern Canada (Rune 1954) and from Scandinavia (Rune 1953); no data on nickel accumulation for these occurrences are available. *Arenaria obtusiloba* is another widespread sandwort, ranging from Alaska across North America to the Gaspé and Greenland. Though it is not wholly restricted to ultramafics, it is a highly faithful indicator of ultramafics in the Wenatchee Mountains (Kruckeberg 1969), the source of the present samples.

Preliminary reports of Roberts (1979, 1980) have indicated that two other species of *Arenaria, A. humifusa* Wahlenb. and *A. marcesens* Fern. from a serpentine area in western Newfoundland, Canada, can also be classified as hyperaccumulators, with nickel con-

TABLE 1. METAL CONCENTRATIONS IN WHOLE PLANTS OF *ARENARIA RUBELLA* AND *A. OBTUSILOBA* COLLECTED IN WASHINGTON STATE.

				(μg g^{-1} dry weight)					
Species	Locality	Rock type	n	Ni	Cr	Co	Fe	Mg	Ca
A. rubella	Skagit County	Dunite	3	1360.0	213.0	33.5	28,900	63,700	5260
A. rubella	Jefferson County	Shale	1	2.7	3.0	0.5	600	1480	19,000
A. obtusiloba	Kittitas County	Peridotite	1	104.0	15.7	6.4	1220	14,600	13,500

TABLE 2. ANALYSIS OF TWO DUNITE SOILS, OLIVINE BRIDGE AREA, SKAGIT COUNTY, WASHINGTON.

	μg/g of dry weight soil					
Collection number	Ni	Cr	Co	Mg	Fe	Ca
Olivine Bridge						
6660	1393	266	82.7	48,120	92,054	2629
Standard deviation	38.3	40.0	3.27	1161	1394	136
Coefficient of variation (%)	(2.75)	(15.0)	(3.95)	(2.41)	(1.51)	(5.18)
6662	2643	98.0	77.6	59,741	66,638	1944
Standard deviation	90.2	17.1	3.00	1951	1378	471
Coefficient of variation (%)	(3.41)	(17.4)	(3.86)	(3.27)	(2.07)	(24.2)

centrations of 2330 and 2365 $\mu g\ g^{-1}$ (dry weight), respectively. The absence of hyperaccumulation in *A. obtusiloba* in the present study, however, reveals that this phenomenon does not occur in all members of the genus. Other *Arenaria* species are found on serpentine locations in Scandinavia (Rune 1953). Although not hyperaccumulators of nickel, they are likely to be adapted physiologically to the nickel-rich substrates by either accumulating or excluding nickel (Shaw 1989).

Data on nickel hyperaccumulators from various sources worldwide suggest a taxonomic bias at the genus and family level. Hyperaccumulators are found in the mustard family, Brassicaceae (Cruciferae), with exceptional frequency (Brooks 1987; Reeves et al. 1981, 1983; Roberts 1980). Although nickel-tolerant and nickel-accumulating races of *Silene, Cerastium* and *Arenaria* (*Minuartia*) have been reported within the Caryophyllaceae, these races have not to date been recorded as hyperaccumulators. As more chemical data on them become available, correlations between taxonomic groupings and affinity for heavy metals are likely to emerge. Such is the case for *Alyssum* (Brassicaceae) in which some 14 species found on European serpentine soils are hyperaccumulators of nickel (Brooks and Radford 1978). Clearly, examination of the various physiological mechanisms permitting hyperaccumulation is required to understand this presumed adaptive phenomenon. This sequestering of accumulated heavy metals is one way plants may avoid the toxic effects of the element (Baker and Walker 1989).

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Appendix I.

Other Collections Analyzed for Heavy Metal Accumulation

None were hyperaccumulators of nickel. Data available from first author (ARK).

Skagit Co., Washington

A. Olivine Bridge area, South Fork Nooksack River, ultramafic (dunite) soil: *Pteridium aquilinum, Achillea millefolium, Elymus glaucus, Adiantum aleuticum, Aspidotis densa, Silene paradoxa* (introduced "founder" population), *Carduus acanthoides* (weed), *Cerastium arvense, Silene menziesii, Prunella vulgaris* (introduced), *Fragaria virginiana* var. *crinita, Pseudotsuga menziesii, Juniperus communis, Pinus contorta, Gaultheria shallon, Alnus rubra, Spiraea menziesii, Ledum groenlandicum, Menziesia ferruginea.*

B. West of Olivine Bridge, non-ultramafic soil (mostly on argillite): *Adiantum aleuticum, Pteridium aquilinum, Pseudotsuga menziesii.*

C. Fidalgo Head, 5 miles west of Anacortes, on ultramafic soil (alpine peridotite): *Juniperus scopulorum, Arbutus menziesii, Aspidotis densa.*

Kittitas Co., Washington

A. Eldorado Creek area, upper North Fork Teanaway River, ultramafic (serpentinized peridotite) soil: *Adiantum aleuticum* (I), *Aspidotis densa* (I), *Polystichum lemmonii* (E), *Chaenactis thompsonii* (E), *Anemone drummondii* (I), *Douglasia dentata nivalis* (I), *Lomatium cuspidatum* (E), *Poa curtifollia* (E), *Eriogonum pyrolaefolium coryphaeum* (I), *Silene parryi, Achillea millefolium lanulosa, Pseudotsuga menziesii, Pinus contorta, P. ponderosa, Juniperus communis, Pinus albicaulis, Abies lasiocarpa, Taxus brevifolia, Ledum columbianum, Salix brachycarpa* (I).

B. Below Eldorado Creek area, non-ultramafic soils: *Pseudotsuga menziesii, Pinus ponderosa.*

E = ultramafic endemic; I = indicator of ultramafics, but non restricted thereto.